Effect of Darkness on the Capacity of Long-Term Freeway Reconstruction Zones

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ABSTRACT

This paper presents an investigation into the effect of darkness on freeway capacity at long-term reconstruction sites. It is part of ongoing research to examine the factors that affect freeway capacity at work zones. Capacity data from two work sites in Ontario, Canada were examined. At each site, capacity observations during the PM peak period were recorded on weekdays before and after the change from Eastern Daylight Time to Eastern Standard Time. Data from video records were then processed using 5-min intervals. Heavy vehicles were converted to passenger car equivalents using the HCM equivalency factors.

Study results suggest that darkness has a significant effect on freeway capacity at freeway reconstruction work zones. However, darkness affected capacity differently at the two sites investigated. At one site, the decline in freeway capacity due to darkness was found to be 7.5% while this decline was found to be only 3.25% at the other site. The study linked this difference to the effect of grade at the second site. This, in turn, suggests that the compound effect of two or more variables on freeway capacity at reconstruction sites is interactive rather than additive, which is consistent with findings from previous stages of this research.

1. INTRODUCTION

In the last two decades, the shift from building new highway facilities to maintaining and upgrading existing ones has been on the rise. This shift has mainly been induced by the ever-increasing traffic demand on the already-congested highway systems and the simultaneous decline in funding new highway projects. While this shift is being viewed as inevitable to meet the new social and economic realities, road maintenance and reconstruction usually cause serious disruptions to traffic thus resulting in negative impacts on the economy, environment and human productivity.

One of the most effective strategies to mitigate the impacts of maintenance and reconstruction on existing highways is to perform these activities during the night when traffic demand usually reaches its lowest daily levels. From a demand-supply point of view, the nighttime work strategy addresses the demand side of the equation by exploiting the daily variation in traffic demand. However, the supply side of the equation is still only approximate, because in current practice daytime and nighttime are treated equally when estimating capacity. Our hypothesis was that darkness affects drivers' visibility (in a similar

way to inclement weather) thus affecting traffic stream characteristics (speeds and headways) which would result in lower capacities.

Most previous research on the effects of darkness investigated the issues of night visibility and traffic safety. Only limited efforts have been made to investigate the effect of darkness on capacity. The only study to directly address the effect of darkness on freeway capacity was conducted in Germany by Brilon and Ponzlet (1995), but they were not considering construction zones. They found anywhere from a 13% to a 25% reduction in capacity under dry conditions between daylight and dark. One study conducted in Britain by the Transport and Road Research Laboratory (TRRL) investigated the impact of darkness on the capacity of road junctions. The study found that the maximum flow through the types of junctions investigated (traffic signals, roundabouts, and major/minor priority junctions) was significantly reduced in darkness (Burrow 1986). Also, the effect of lighting on freeway capacity during nighttime was investigated by a study in the Netherlands (Botma et al. 1998). The study reported that a reduction in nighttime capacity of 7.2% on two-lane directional freeways and 4.7% on three-lane directional freeways was noticed in the absence of lighting. Finally, another empirical study found that low visibility due to poor environmental conditions is usually accompanied by a reduction in travel speeds (Liang et al. 1998). This would logically lead to a lower capacity if headways remained constant or even decreased by smaller proportions.

The paper is organized in four parts following this introduction. Section 2 describes the work zone configuration of the selected sites and their location. A description of data collection and reduction process is provided in Section 3. Then, Section 4 presents data analysis at each individual site and Section 5 summarizes the most important findings and conclusions.

2.   SELECTION AND DESCRIPTION OF STUDY SITES

Two sites in Ontario, Canada were investigated by this research. The first site is located on Highway 403 westbound (HWY 403-WB) in the eastern part of the city of Hamilton while the second site is located on the Queen Elizabeth Way westbound (QEW-WB) in the city of Burlington. Both sites have significant traffic during the PM peak as many residents in Hamilton and the surrounding area commute eastbound in the morning to their place of work in or near the city of Toronto.

Recently, these two sites underwent major reconstruction works (where the activity area was separated from the traveled lanes by temporary concrete barriers) and therefore they were considered good candidates for this study. A schematic layout of each reconstruction site is provided in Figure 1.

On the 403-WB, the construction activity took place only on the right side. The left shoulder was unaffected during construction. The approximate length of the affected area was 800 m, which was located on a slight downgrade through the data collection site.

On the QEW-WB site, construction activity took place on both sides, and both the right and left shoulders were closed during construction. The approximate length of the affected

area at this site was 500 m. This site involves a local upgrade and downgrade as it includes a bridge that passes over rail tracks.

Both sites have normal lane width and geometrics as well as good high-mast lighting (during nighttime) at the affected freeway areas. Downstream of the construction area at each site there is a major exit ramp with a deceleration lane of considerable length. The two reconstruction sites allowed the observation of the upstream queue during the PM peak. Also, it was easy to identify unusual events that took place on the freeway or on the work site.
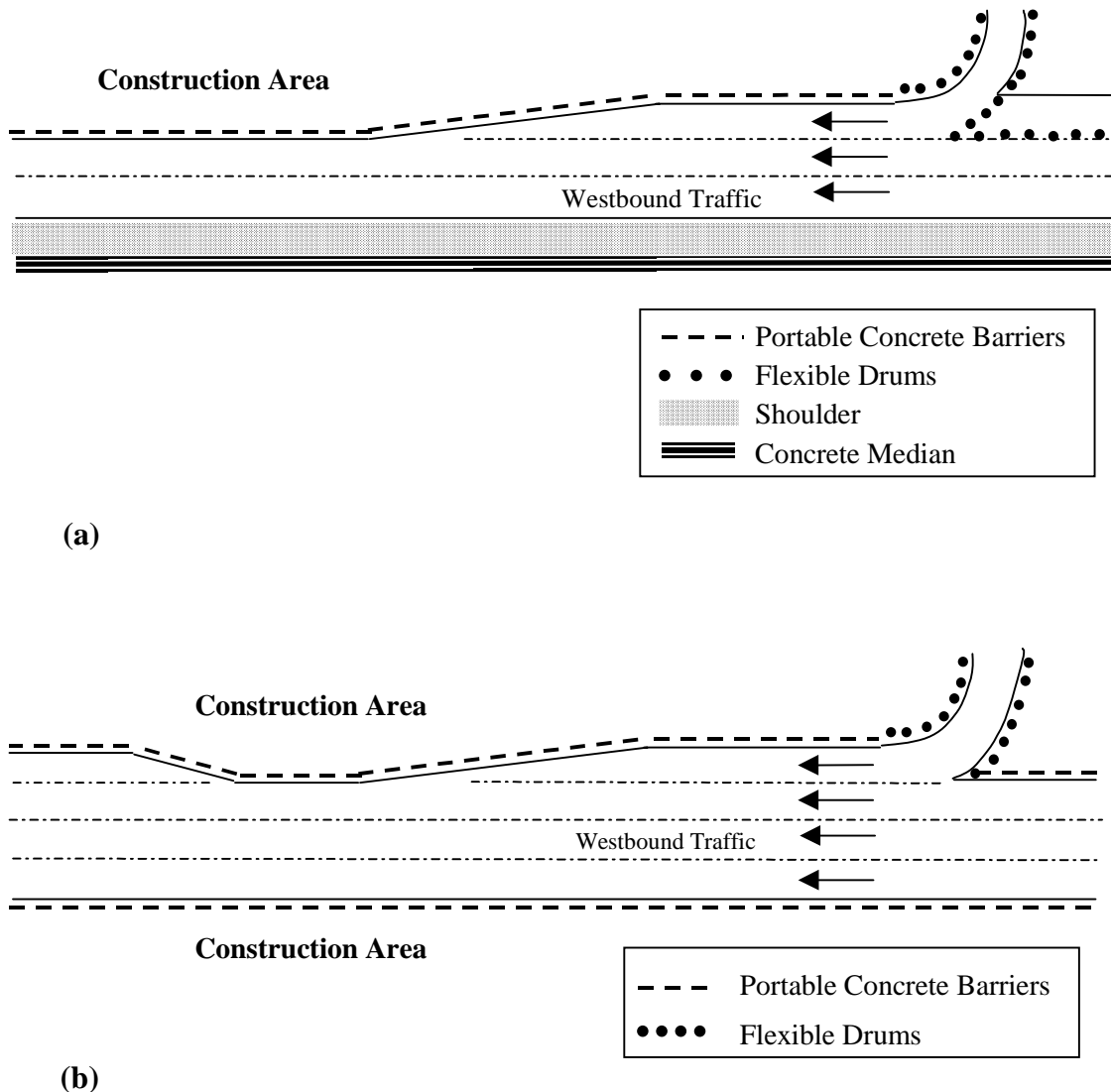

(a)

(b)

FIGURE 1   Schematic layout of work site configuration: (a) HWY 403-WB, (b) QEW-WB.

3.   DATA COLLECTION AND PROCESSING

Capacity observations were recorded at the study sites during the afternoon peak period on weekdays when queuing (congested traffic operation) was present. Fourteen data sets totaling around 21 h of capacity observations were recorded at the two sites on different weekdays, before and after the change from Eastern Daylight Time to Eastern Standard Time. It is important to note that the time of day when the data were collected did not change—only the light conditions did. These are in large measure the same drivers at a site, simply under different lighting conditions. Only about 17 h of capacity observations were used in this research. Data screening was performed and resulted in excluding about 19% of the data, due to situations that may affect the validity of capacity measurements. These situations included:

1. Vehicle breakdown in the traffic stream prior to the construction area at QEW-WB on October 1, 1999

2. Traffic accident that occurred downstream of the 403-WB site on October 21, 1999 (freeway at the work zone became part of the queue)

3. Configurations at 403-WB site that are different from the one shown in Figure 1 (two data sets)

4. The transition between forced-flow and free-flow regimes (usually at the start or end of video recording)

5. The transition from daylight to dark during sunset.

Traffic data was collected using video recording. The data was then processed manually and recorded using 5-min traffic counts. Hourly flow rates were calculated from these 5-min volumes. This time interval represents a trade off between two important requirements: having sufficient amount of observations for statistical analyses and keeping the random variation in capacity counts to an acceptable level. In this study, the 5-min interval was deemed long enough to smooth out the random fluctuation in capacity counts that would typically happen with shorter time intervals (20 sec or even 1 min). Also, a 5-min interval was considered more appropriate than longer intervals in that an adequate number of observations can be made available for the subsequent statistical analyses.

Three generic vehicle categories were used in data processing, namely, passenger cars, trucks and recreational vehicles. This classification was considered to allow for the use of the HCM equivalency factors in order to convert capacity counts from vphpl (vehicle per hour per lane) to pcphpl (passenger car per hour per lane). A factor of 1.5 was used for trucks and buses and 1.2 for recreational vehicles (these factors are provided in the Table 3-2 page 3-16 of the HCM 1997). This conversion of heavy vehicles into passenger cars, while recognized to have limitations, was deemed more accurate than using mixed-vehicle counts. The percentage of heavy vehicles (trucks and buses) was found to be around 9% of total traffic at the QEW-WB site and only around 4% of total traffic at the 403-WB site during the times investigated.

4.   DATA ANALYSIS

Capacity data were analyzed at each site independently and the results are presented in the following sections.

4.1   Site 1: Highway 403 Westbound

4.1.1   Aggregate capacity observations

The mean capacity value at this site was found to be around 2200 pcphpl. This value of work zone capacity is considered relatively high when compared to capacity values that are provided in the *Highway Capacity Manual* (TRB 1998) or those reported in the previous stages of this research (Al-Kaisy et al. 1999). This difference in capacity can be attributed to several factors. First and most important is that, unlike the capacity values referred to above, capacity in this research was measured in passenger car equivalents and therefore the effect of heavy vehicles was taken into account. Another factor that might have contributed to this difference is that the construction activity at this site took place on the right side only while the wide left shoulder remained unaffected during construction (Figure 1). Moreover, a significant part of the capacity observations at this site occurred with no construction activity taking place at the roadside (construction was active during part of the daytime observations only). The impact of this factor on capacity will be discussed in the following section.

The standard deviation and the coefficient of variation (defined as the standard deviation divided by the mean and expressed as a percentage) for capacity observations were 112 pcphpl and 5%, respectively. The variation of these aggregate capacity observations will be compared later with that of the daylight and darkness observations.

The frequency distribution of aggregate capacity observations at this site and the normal curve are shown in Figure 2. A normality test was conducted and it confirmed that the distribution largely follows the normal curve. Specifically, the ratio of skewness and kurtosis statistics to their standard errors are well below 2.5 and therefore the distribution of capacity observations shown in this figure is considered compliant with the normal distribution (Morgan and Griego 1998). Table 1 shows the SPSS output statistics for the frequency distribution of capacity observations at 403-WB site and QEW-WB site.

4.1.2   Capacity observations by day and night

Capacity observations during the day were recorded both in the presence and in the absence of construction activity. Therefore, it was important to examine this factor before any analysis on aggregate daytime observations could be made. As expected, the mean capacity value for daytime observations with ongoing construction at the site was found to be less than the corresponding mean capacity value with no construction at the site (2232 pcphpl versus 2251 pcphpl). On the other hand, the variation in capacity during construction was found to be higher than the variation in the absence of construction. The standard deviation and the coefficient of variation was found to be 91 pcphpl and 4.1% for the first group of observations versus 80 pcphpl and 3.5% for the second group.
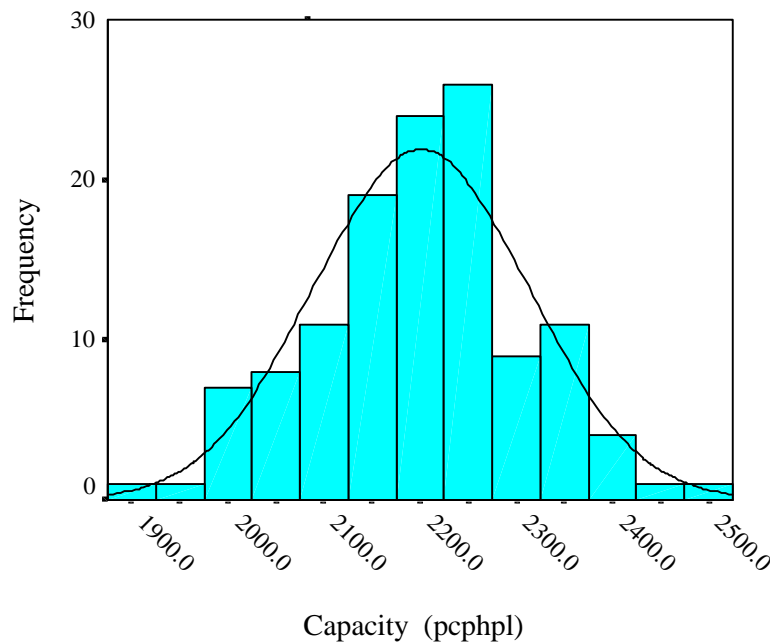
FIGURE 2   Frequency distribution of aggregate capacity observations at site 1.

From these preliminary findings, it was important to decide whether there is significant difference between average capacity values and their variation in the presence and in the absence of construction activity. An *f*-test confirmed that the variation of capacity observations during construction is significantly higher than that recorded in the absence of construction activity (at the 95% confidence level). This may be attributed in part to the variable nature of construction activity and therefore variable degree of restriction to traffic stream at the affected zone. Also, different driver behavior in response to the distraction caused by this activity might be behind some of this variation. As for the mean capacity values, a *t*-test (for two samples with unequal variances) was conducted on these two groups of observations and it showed that there is no significant difference between the mean values at the 95% confidence level. The mean capacity value of aggregate

TABLE 1   Summary Statistics on the Frequency Distribution of Aggregate Capacity Observations at the Sites Investigated

	HWY 403-WB	QEW-WB
No. of Observations	123	80
Mean	2201	1831
Median	2208	1828
Std. Deviation	112	86
Skewness	-0.125	-0.042
Std. Error of Skewness	0.218	0.269
Skewness/Std. Error of skewness	-0.57	-0.156
Kurtosis	0.033	-0.277
Std. Error of Kurtosis	0.433	0.532
Kurtosis/Std. Error of Kurtosis	0.076	-0.52

daytime observations was found to be 2247 pcphpl with a standard deviation of 83 pcphpl and a coefficient of variation of 3.7%.

Nighttime observations were all recorded while there was no active construction work at the site. However, the analysis of daytime observations showed that this factor has no significant impact on the mean capacity values at this site. The mean capacity value during the nighttime at this site was found to be 2079 pcphpl. The variation in capacity during day and night was tested using an *f*-test and it was found that there was no significant difference in the variance of the two groups (at the 95% confidence level). A *t*-test was also conducted on these two groups of observations and it confirmed that the mean capacity value during the night is significantly lower than that during the day at the 95% confidence level. These results are shown in Table 2. The decrease in work zone capacity due to darkness was found to be around 7.5%. This reduction in capacity values is evident in Figure 3 which shows the cumulative percentile distribution of capacity observations by day and night. This figure shows clearly that daylight and darkness have different frequency distributions. This also explains why the aggregate standard deviation is around 112 pcphpl whereas those for each subset are roughly 83 pcphpl.

The variation in capacity values during the night was close to that observed during the day. The standard deviation and coefficient of variation were 82.3 pcphpl and 3.9% during the day versus 83 pcphpl and 3.7% during the night. However, this variation was lower than that of the aggregate capacity observations and this represents another indication that capacity values are different in daylight and in darkness.

4.2   Site 2: QEW Westbound at Burlington

4.2.1   Aggregate capacity observations

At this site, all daylight and darkness capacity observations were recorded while there was ongoing construction activity. However, this activity was generally taking place at some distance from the traveled lanes on elevated earthworks for most of the site. As such, no serious impact on traffic due to construction is expected.

TABLE 2   *t*-Test Results for Comparison of Means of Daylight and Darkness Observations at the Sites 403-WB and QEW-WB

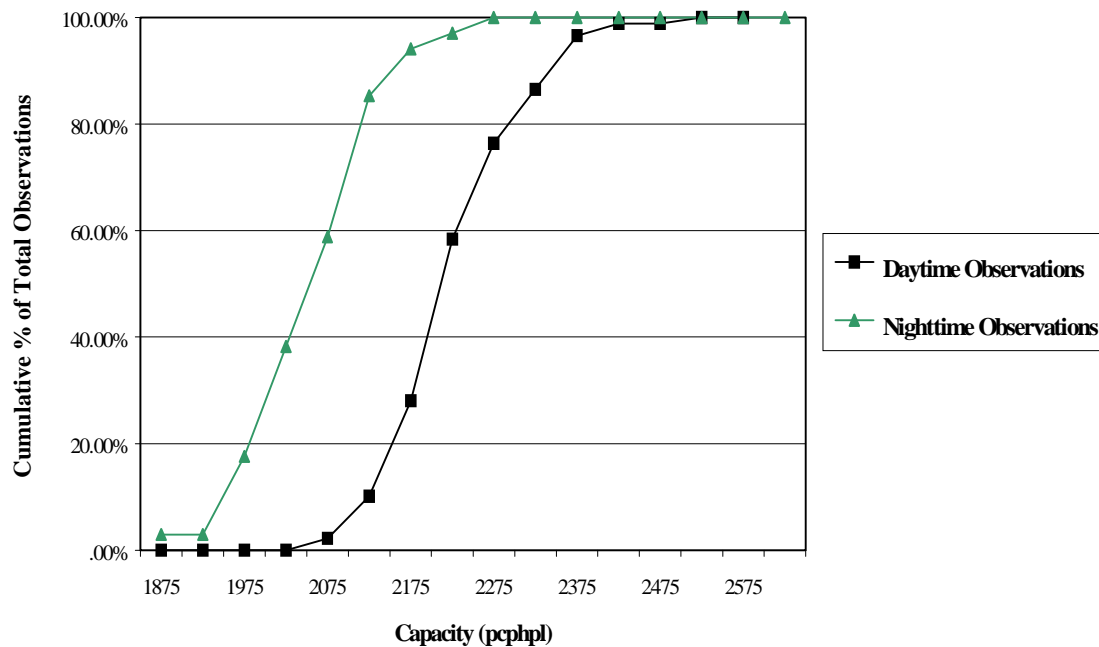|	HWY 403-WB	QEW-WB
Daylight mean	2252	1853
Daylight variance	6466	6712
Darkness mean	2079	1793
Darkness variance	6775	6518
No. of daylight observations	68	51
No. of darkness observations	34	29
t Stat	10.07	3.15
$P(T \le t)$ one-tail	3.4E-15	0.001

FIGURE 3   Cumulative percentile distribution of capacity observations at site 1 (by day and night).

The mean capacity value at this freeway reconstruction site was 1831 pcphpl. This mean value is considerably lower than those found at the previous site. This is expected as the work zone configuration at this site is more restrictive than that of the previous site. Specifically, both shoulders are closed with construction taking place on both roadsides. Also, this site involves an upgrade and this imposes additional restriction on traffic flow particularly at higher percentages of heavy vehicles (heavy vehicles formed around 9% of total traffic at this site during the times investigated).

As for the variation in capacity observations, results show that the variation at this site is higher than that at the other site (a coefficient of variation of 4.7% versus 3.6%). However, a comparison of variances using an *f*-test showed that this difference is not significant at the 95% confidence level.

The frequency distribution of aggregate capacity observation at this site was established as shown in Figure 4. Also, a test of normality was conducted and it confirmed that the distribution generally follows the normal curve (see Table 1).

4.2.2   Capacity observations by day and night

The average capacity value at this site during the night was found to be lower than the corresponding average value during the day: 1853 pcphpl in the daytime versus 1793 pcphpl in the nighttime. This corresponds to a 3.25% reduction in capacity due to darkness at this site. A *t*-test was conducted and confirmed that the difference in mean capacity values between day and night is significant at the 95% confidence level. The results are shown in Table 2. This difference in capacity values is illustrated in Figure 5. This figure shows the cumulative percentile distribution of capacity observations at this site by day and night.
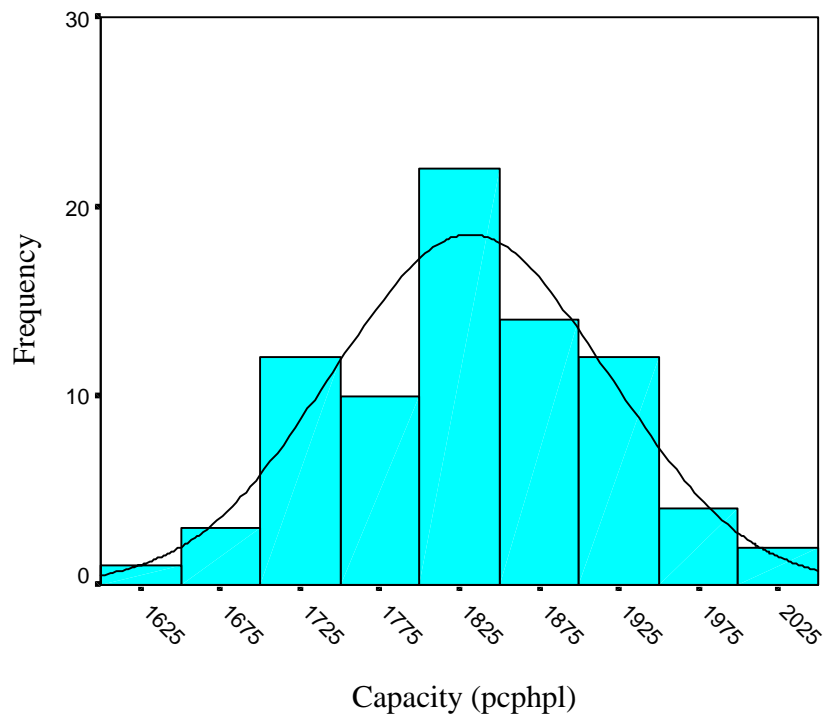
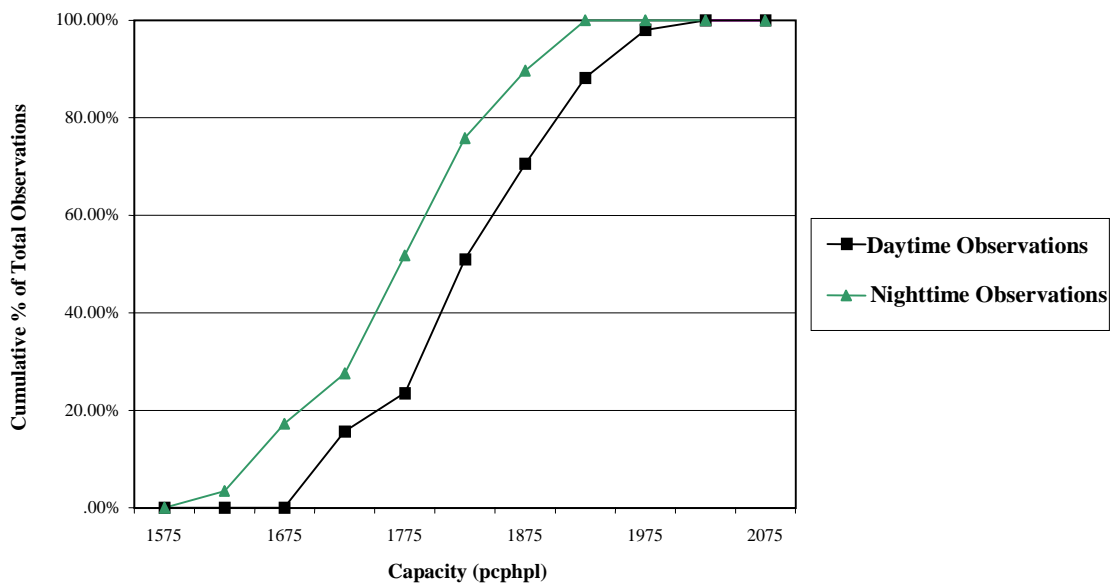**FIGURE 4   Frequency distribution of aggregate capacity observations at site 2.**

FIGURE 5   Cumulative percentile distribution of capacity observations at site 2 (by day and night).

5.   SUMMARY OF FINDINGS

This paper presented an investigation into the effect of darkness on freeway capacity at long-term reconstruction sites. Two work sites in Ontario, Canada were selected for this investigation. Capacity data were collected from these two sites during the PM peak period on different weekdays. Both sites have good lighting during nighttime. In this paper, no comparisons were made with previous studies as the conditions investigated by those studies are not similar. While the present study investigated freeway capacity during daytime and nighttime on well-lit freeways, the study by Brilon and Ponzlet (1995) investigated the capacity during daytime and nighttime on freeways with no lighting. Also, the study by Botma et al. (1998) investigated freeway capacity during nighttime both with and without lighting.

The most important finding of this investigation is that there was a significant reduction in work zone capacity due to darkness at both sites, or in other words, darkness has a significant effect on freeway capacity at long-term reconstruction work zones. This effect has been largely overlooked in current practice.

The decline in average capacity value was about 7.5% at the first site and only about 3.25% at the second site. This suggests that darkness affected freeway work zone capacity differently at the two sites. Although it would be satisfying to be able to construct a confidence interval for the capacity reduction, it was not possible in this case as the data did not involve paired observations, and therefore there was not a distribution of differences. One interpretation of the different effects on capacity observed at the two sites is that, at the second site, both the grade effect and darkness simultaneously affected work zone capacity during nighttime. In previous stages of this research, results suggested that the compound effect of two or more variables on work zone capacity is mostly interactive rather than additive (Al-Kaisy et al. 1999). This may explain the different extents to which capacity was penalized by darkness at the previous two sites. Despite the different capacity reductions at the two sites investigated by this study, it would be appropriate to expect roughly a 5% reduction in capacity during nighttime hours, for a facility with good lighting. However, it should be remembered that these results are preliminary, and that there are clearly a number of other confounding variables that were not possible to analyze within these data.

The study results also suggest that capacity at the QEW-WB site may have been penalized by the presence of heavy vehicles when compared to that at the other site (9% on QEW-WB versus 4% on 403-WB). In particular, the higher percentage of heavy vehicles as well as the grade effect may have contributed to the difference in capacity values. Furthermore, some of the difference might be attributed to the HCM equivalency factors used. These factors are intended to be used for free-flow conditions and therefore may underestimate the impact of heavy vehicles in congested (or stop-and-go) conditions. This calls for an investigation into the effects of heavy vehicles on a traffic stream during congestion so that a more realistic procedure can be used to account for this important factor.

ACKNOWLEDGMENT

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